FIG.1A

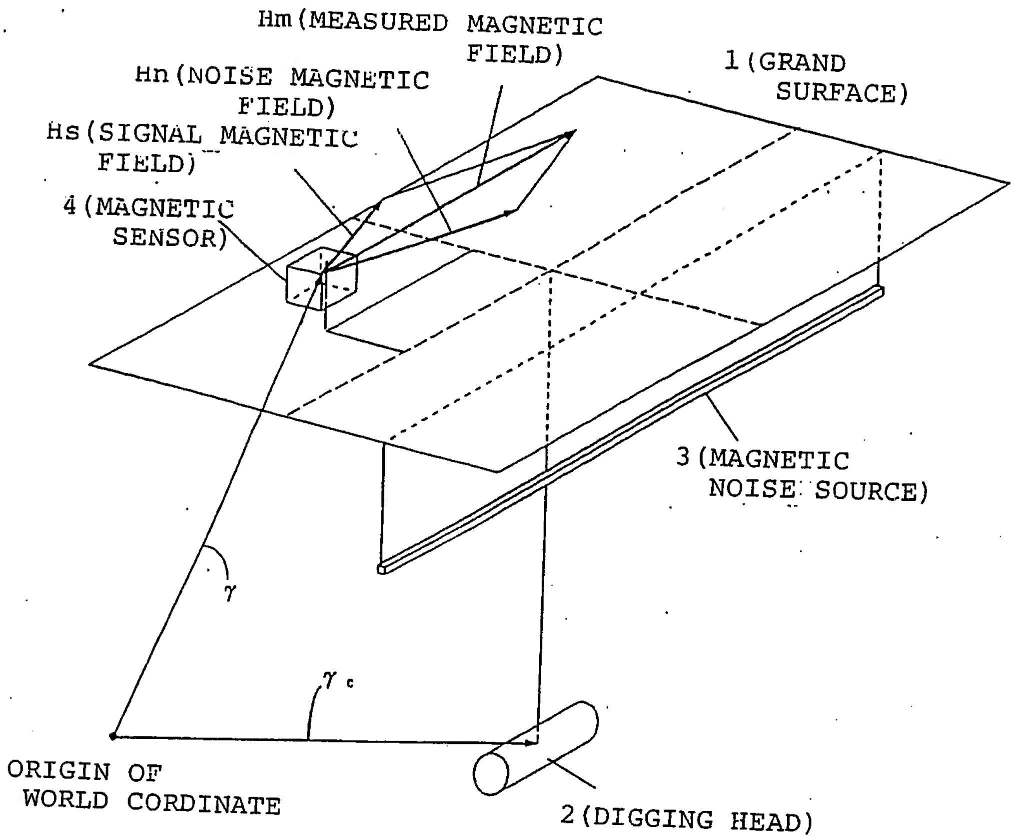

Hm(MEASURED MAGNETIC FIELD)
Hn(NOISE MAGNETIC FIELD)
Hs(SIGNAL MAGNETIC FIELD)
4(MAGNETIC SENSOR)
1(GRAND SURFACE)
3(MAGNETIC NOISE SOURCE)
γ
γ c
ORIGIN OF WORLD CORDINATE
2(DIGGING HEAD)

FIG.1B

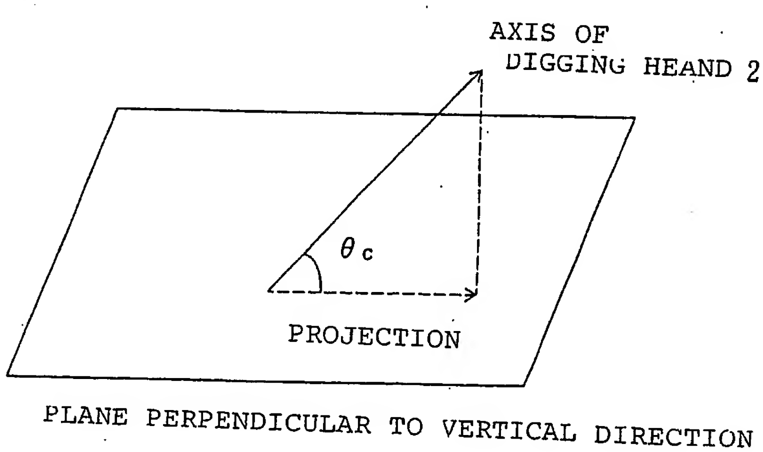
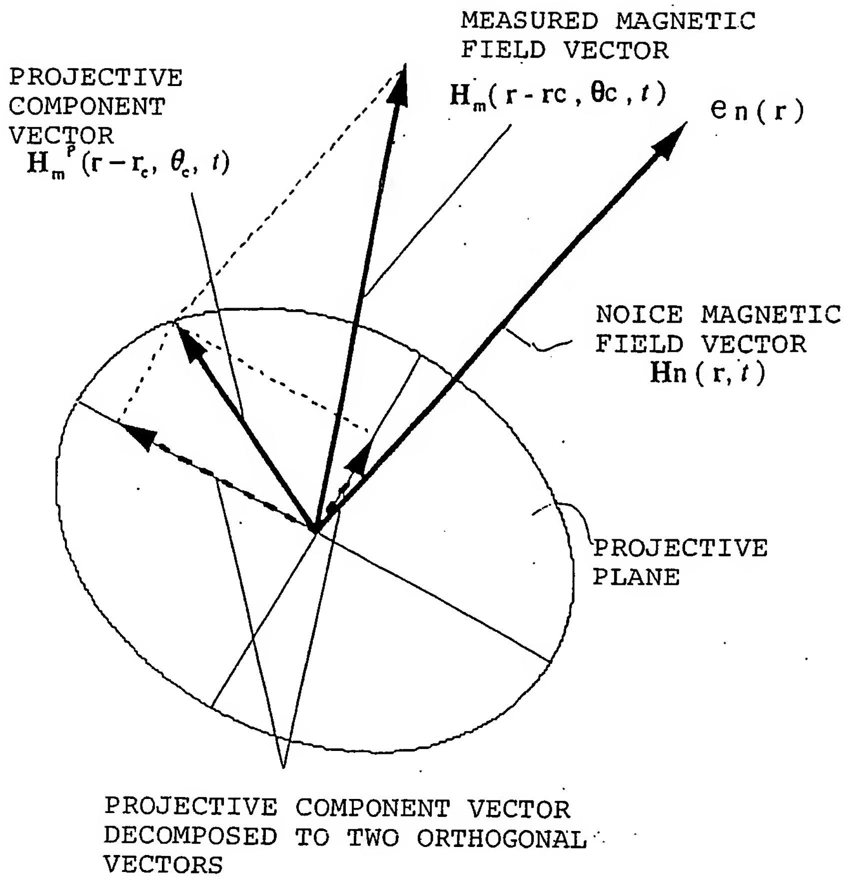

AXIS OF DIGGING HEAND 2
θ c
PROJECTION
PLANE PERPENDICULAR TO VERTICAL DIRECTION

FIG.2



MEASURED MAGNETIC FIELD VECTOR
$H_m(r - rc, \theta c, t)$
PROJECTIVE COMPONENT VECTOR
$H_m^P(r - r_c, \theta_c, t)$
$e_n(r)$
NOICE MAGNETIC FIELD VECTOR
$Hn(r, t)$
PROJECTIVE PLANE
PROJECTIVE COMPONENT VECTOR DECOMPOSED TO TWO ORTHOGONAL VECTORS

FIG.3

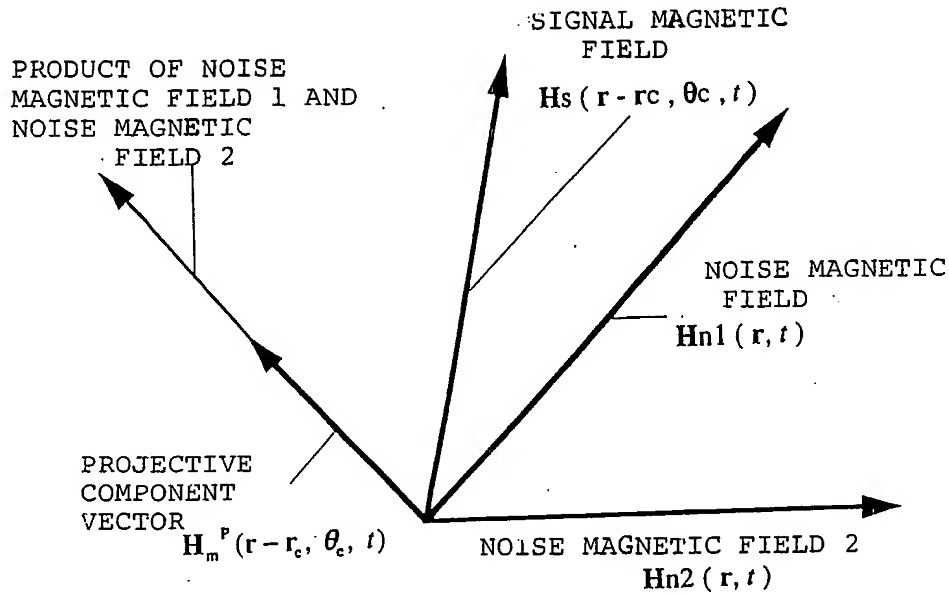

SIGNAL MAGNETIC FIELD
Hs (r - rc , θc , t)
PRODUCT OF NOISE MAGNETIC FIELD 1 AND NOISE MAGNETIC FIELD 2
NOISE MAGNETIC FIELD
Hn1 (r, t)
PROJECTIVE COMPONENT VECTOR
$H_m^P(r - r_c, \theta_c, t)$
NOISE MAGNETIC FIELD 2
Hn2 (r, t)

FIG.4

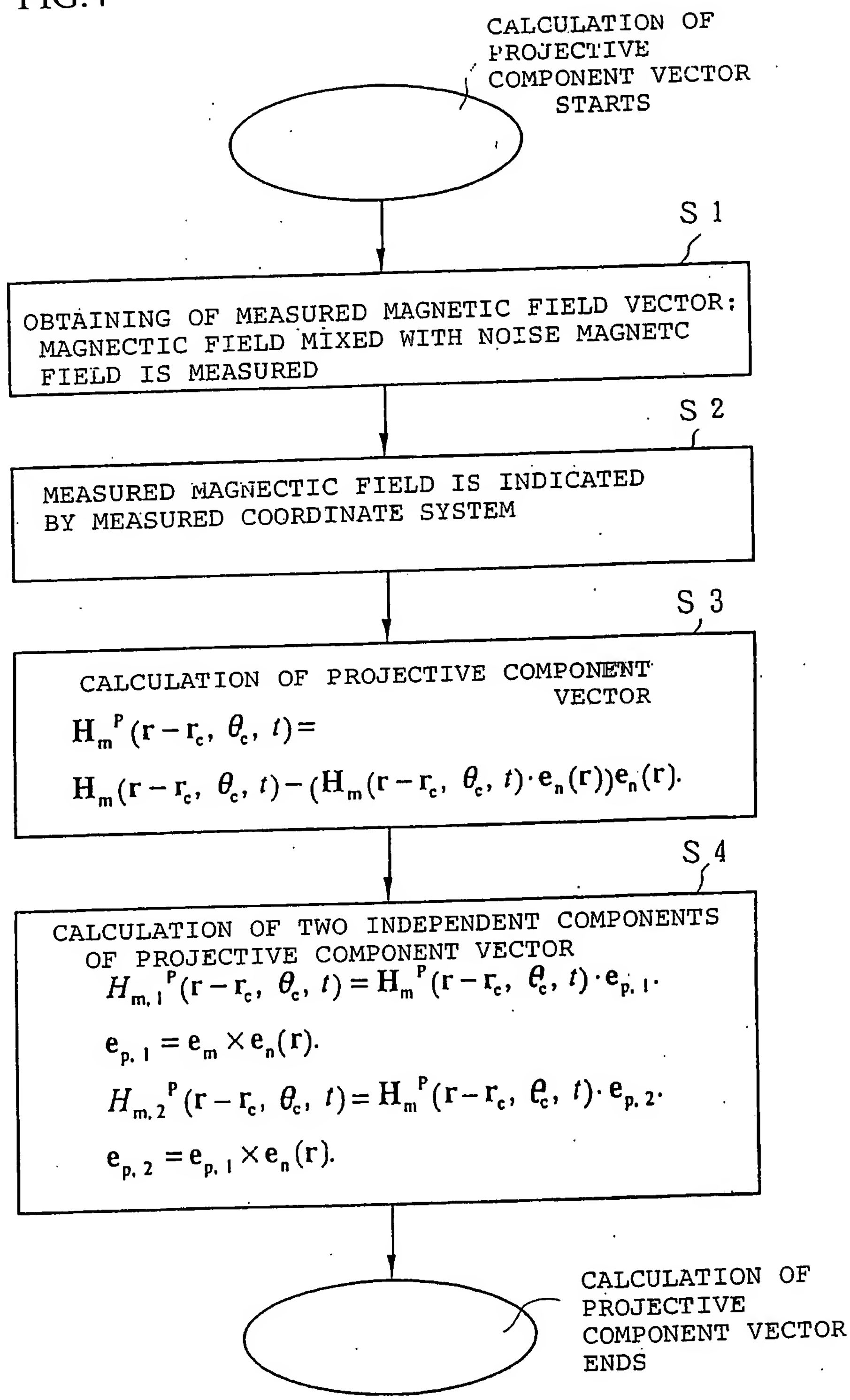

CALCULATION OF PROJECTIVE COMPONENT VECTOR STARTS
S 1
OBTAINING OF MEASURED MAGNETIC FIELD VECTOR: MAGNECTIC FIELD MIXED WITH NOISE MAGNETC FIELD IS MEASURED
S 2
MEASURED MAGNECTIC FIELD IS INDICATED BY MEASURED COORDINATE SYSTEM
S 3
CALCULATION OF PROJECTIVE COMPONENT VECTOR
$\mathbf{H}_m{}^P(\mathbf{r}-\mathbf{r}_c, \theta_c, t)=$
$\mathbf{H}_m(\mathbf{r}-\mathbf{r}_c, \theta_c, t)-(\mathbf{H}_m(\mathbf{r}-\mathbf{r}_c, \theta_c, t)\cdot\mathbf{e}_n(\mathbf{r}))\mathbf{e}_n(\mathbf{r}).$
S 4
CALCULATION OF TWO INDEPENDENT COMPONENTS OF PROJECTIVE COMPONENT VECTOR
$H_{m,1}{}^P(\mathbf{r}-\mathbf{r}_c, \theta_c, t)=\mathbf{H}_m{}^P(\mathbf{r}-\mathbf{r}_c, \theta_c, t)\cdot\mathbf{e}_{p,1}.$
$\mathbf{e}_{p,1}=\mathbf{e}_m\times\mathbf{e}_n(\mathbf{r}).$
$H_{m,2}{}^P(\mathbf{r}-\mathbf{r}_c, \theta_c, t)=\mathbf{H}_m{}^P(\mathbf{r}-\mathbf{r}_c, \theta_c, t)\cdot\mathbf{e}_{p,2}.$
$\mathbf{e}_{p,2}=\mathbf{e}_{p,1}\times\mathbf{e}_n(\mathbf{r}).$
CALCULATION OF PROJECTIVE COMPONENT VECTOR ENDS

FIG.5

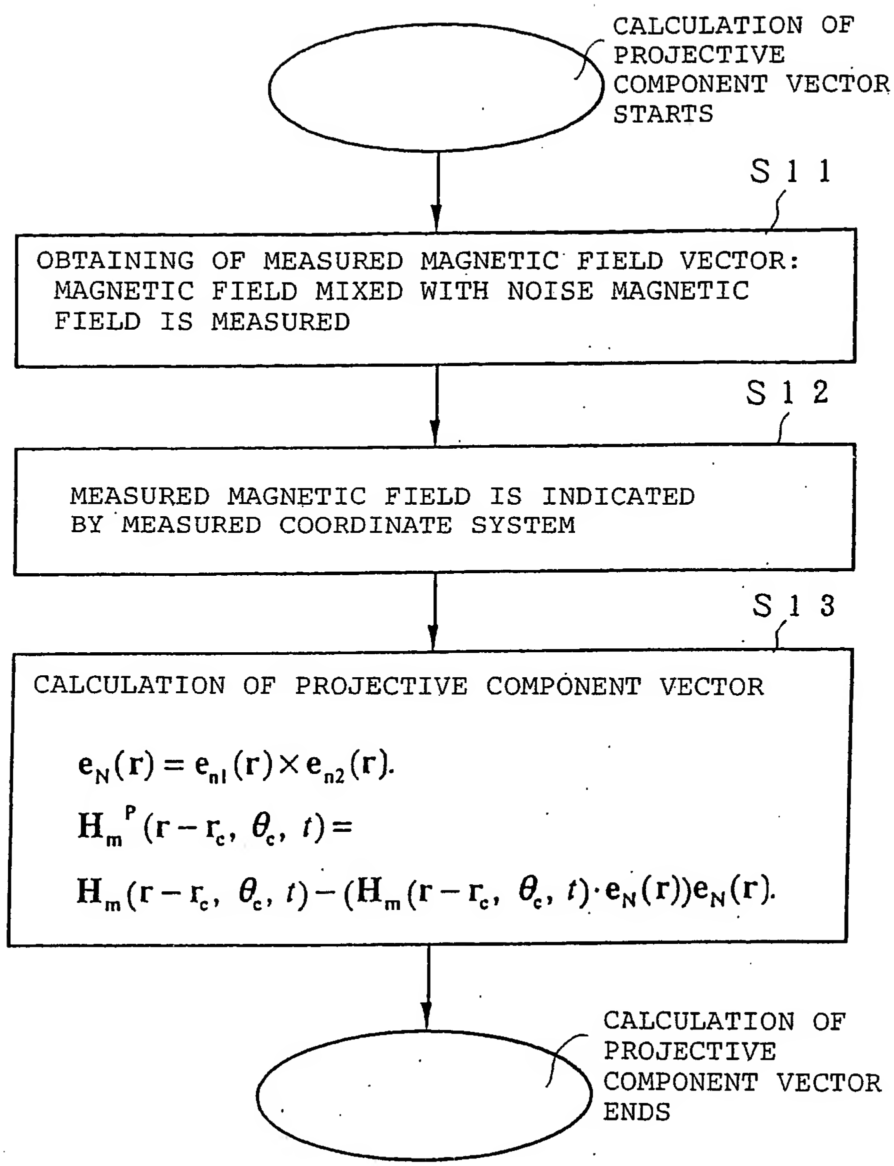

CALCULATION OF PROJECTIVE COMPONENT VECTOR STARTS
S11
OBTAINING OF MEASURED MAGNETIC FIELD VECTOR: MAGNETIC FIELD MIXED WITH NOISE MAGNETIC FIELD IS MEASURED
S12
MEASURED MAGNETIC FIELD IS INDICATED BY MEASURED COORDINATE SYSTEM
S13
CALCULATION OF PROJECTIVE COMPONENT VECTOR
$e_N(r) = e_{n1}(r) \times e_{n2}(r).$
$H_m{}^P(r - r_c,\ \theta_c,\ t) =$
$H_m(r - r_c,\ \theta_c,\ t) - (H_m(r - r_c,\ \theta_c,\ t) \cdot e_N(r))e_N(r).$
CALCULATION OF PROJECTIVE COMPONENT VECTOR ENDS

FIG.6

CALCULATION OF SIGNAL COMPONENT VECTOR STARTS

S11

OBTAINING OF MEASURED MAGNETIC FIELD VECTOR: MAGNETIC FIELD MIXED WITH NOISE MAGNETIC FIELD IS MEASURED

S12

MEASURED MAGNETIC FIELD IS INDICATED BY MEASURED COORDINATE SYSTEM

S14

CALCULATION OF PROJECTIVE COMPONENT VECTOR

$$\mathbf{H}_m{}^P(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t)=$$

$$\mathbf{H}_m(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t)-(\mathbf{H}_m(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t)\cdot\mathbf{e}_n(\mathbf{r}))\mathbf{e}_n(\mathbf{r}).$$

S15

CALCULATION OF TWO INDEPENDENT COMPONENTS OF PROJECTIVE COMPONENT VECTOR

$$H_{m,1}{}^P(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t)=\mathbf{H}_m{}^P(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t)\cdot\mathbf{e}_{p,1}.$$

$$\mathbf{e}_{p,1}=\mathbf{e}_m\times\mathbf{e}_n(\mathbf{r}).$$

$$H_{m,2}{}^P(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t)=\mathbf{H}_m{}^P(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t)\cdot\mathbf{e}_{p,2}.$$

$$\mathbf{e}_{p,2}=\mathbf{e}_{p,1}\times\mathbf{e}_n(\mathbf{r}).$$

S16

CALCULATION OF SIGNAL COMPONENT VECTOR

$$\mathbf{H}_s(\mathbf{r}-\mathbf{r}_c,\ \theta_c)=\langle\mathbf{H}_m(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t)H_m{}^P(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t)\rangle_t.$$

CALCULATION OF SIGNAL COMPONENT VECTOR ENDS

FIG.7

CALCULATION OF SIGNAL COMPONENT VECTOR STARTS

S11

OBTAINING OF MEASURED MAGNETIC FIELD VECTORS: MAGNETIC FIELD MIXED WITH NOISE MAGNETIC FIELD IS MEASURED

S12

MEASURED MAGNETIC FIELD IS INDICATED BY MEASURED COORDINATE SYSTEM

S14a

CALCULATION OF PROJECTIVE COMPONENT VECTOR

$$\mathbf{e}_N(\mathbf{r}) = \mathbf{e}_{n1}(\mathbf{r}) \times \mathbf{e}_{n2}(\mathbf{r}).$$

$$\mathbf{H}_m{}^P(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t) =$$

$$\mathbf{H}_m(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t) - (\mathbf{H}_m(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t)\cdot\mathbf{e}_N(\mathbf{r}))\mathbf{e}_N(\mathbf{r}).$$

S16

CALCULATION OF SIGNAL COMPONENT VECTOR

$$\mathbf{H}_s(\mathbf{r}-\mathbf{r}_c,\ \theta_c) = \left\langle \mathbf{H}_m(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t) H_m{}^P(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t) \right\rangle_t.$$

CALCULATION OF SIGNAL COMPONENT VECTOR ENDS

FIG.8

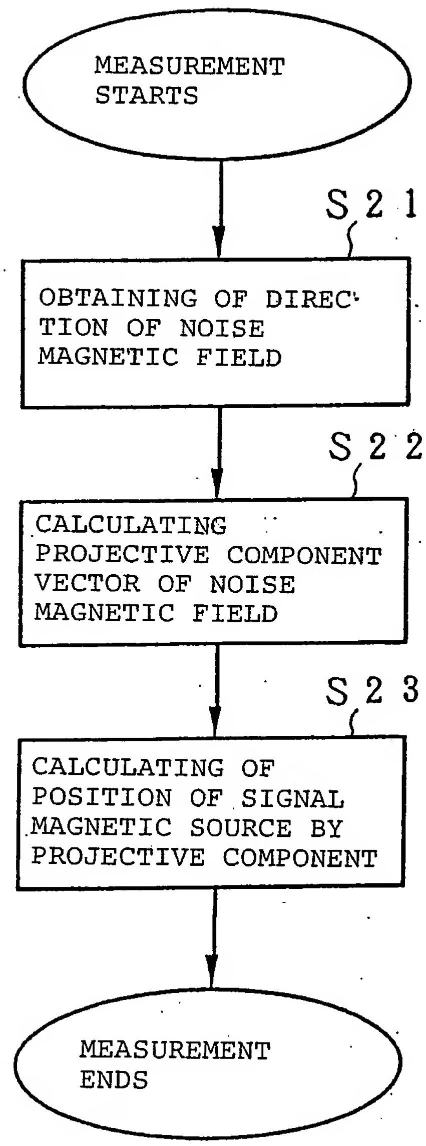

MEASUREMENT STARTS
S21
OBTAINING OF DIRECTION OF NOISE MAGNETIC FIELD
S22
CALCULATING PROJECTIVE COMPONENT VECTOR OF NOISE MAGNETIC FIELD
S23
CALCULATING OF POSITION OF SIGNAL MAGNETIC SOURCE BY PROJECTIVE COMPONENT
MEASUREMENT ENDS

FIG.9

MEASUREMENT STARTS

S31

POSITION AND ORIENTATION OF MAGNETIC FIELD SOURCE IS ASSUMED AND SIGNAL MAGNETIC FIELD IS CALCULATED AT EACH MEASURMENT POSITION

$$\mathbf{H}_e(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t)$$

S32

PROJECTIVE COMPONENT VECTOR OF CALCULATED MAGNETIC FIELD IS CALCULATED

$$\mathbf{H}_e{}^{P}(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t)$$

S33

PROJECTIVE COMPONENT VECTOR OF CALCULATED MAGNETIC FIELD IS DECOMPOSED TO TWO INDEPEND-ENT DIRECTION COMPONENT VECTORS

$$H_{e,q}{}^{P}(\mathbf{r}-\mathbf{r}_c,\ \theta_c),\quad q=1,\ 2$$

S34

POSITION AND AZIMUTH ANGLE OF MAGNETIC FIELD SOURCE, WHERE RESPECTIVE PROJECTIVE COMPONENT VECTORS OF CALCULATED MAGNETIC FIELD AND MEASURED MAGNETIC FIELD ARE THE SAME AS TO EACH OTHER, IS CALCULATED BY RESOLVING THE FOLLOWING EQUATION

$$\left\langle H_{m,q}{}^{P}(\mathbf{r}_k-\mathbf{r}_c,\ \theta_z,\ t)\right\rangle_t - H_{e,q}{}^{P}(\mathbf{r}_k-\mathbf{r}_c,\ \theta_z)=0,\ k=1;\ 2;\ q=1,\ 2.$$

MEASUREMENT ENDS

FIG.10

MEASUREMENT STARTS

S41

POSITION AND ORIENTATION OF MAGNETIC FIELD SOURCE IS ASSUMED AND SIGNAL MAGNETIC FIELD IS CALCULATED AT EACH MEASURMENT POSITION
$\mathbf{H}_c(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t)$

S42

PROJECTIVE COMPONENT VECTOR OF CALCULATED MAGNETIC FIELD IS CALCULATED

$\mathbf{H}_c^{P}(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t)$

S43

PROJECTIVE COMPONENT VECTOR OF CALCULATED MAGNETIC FIELD IS DECOMPOSED TO TWO INDEPENDENT DIRECTION COMPONENT VECTORS
$H_{c,q}^{P}(\mathbf{r}-\mathbf{r}_c,\ \theta_c),\ q=1,\ 2$

S44

POSITION AND AZIMUTH ANGLE OF MAGNETIC FIELD SOURCE, WHERE RESPECTIVE PROJECTIE COMPONENT VECTORS OF CALCULATED MAGNETIC FIELD AND MEASURED MAGNETIC FIELD ARE THE SAME AS TO EACH OTHER, IS CALCULATED BY RESILVING THE FOLLOWING EQUATION

$$\min_{\mathbf{r}_c,\ \theta_c}\left\{\sum_{k=1}^{N_m}\sum_{q=1}^{2} w_{k,q}\left|\left\langle\left|H_{m,q}^{P}(\mathbf{r}_k-\mathbf{r}_c,\ \theta_c,\ t)\right|\right\rangle_t - H_{c,q}^{P}(\mathbf{r}_k-\mathbf{r}_c,\ \theta_c)\right|\right\}.$$

or

$$\min_{\mathbf{r}_c,\ \theta_c}\left\{\sum_{k=1}^{N_m}\sum_{q=1}^{2} w_{k,q}\left|\sqrt{\left\langle\left|H_{m,q}^{P}(\mathbf{r}_k-\mathbf{r}_c,\ \theta_c,\ t)\right|^2\right\rangle_t} - H_{c,q}^{P}(\mathbf{r}_k-\mathbf{r}_c,\ \theta_c)\right|\right\}.$$

or

$$\min_{\mathbf{r}_c,\ \theta_z}\left\{\sum_{k=1}^{N_m}\sum_{q=1}^{2} w_{k,q}\left|\left\langle\left|H_{m,q}^{P}(\mathbf{r}_k-\mathbf{r}_c,\ \theta_c,\ t)\right|\right\rangle_t - H_{c,q}^{P}(\mathbf{r}_k-\mathbf{r}_c,\ \theta_z)\right|^2\right\}.$$

or

$$\min_{\mathbf{r}_c,\ \theta_z}\left\{\sum_{k=1}^{N_m}\sum_{q=1}^{2} w_{k,q}\left|\sqrt{\left\langle\left|H_{m,q}^{P}(\mathbf{r}_k-\mathbf{r}_c,\ \theta_c,\ t)\right|^2\right\rangle_t} - H_{c,q}^{P}(\mathbf{r}_k-\mathbf{r}_c,\ \theta_z)\right|^2\right\}.$$

MEASUREMENT ENDS

FIG.11

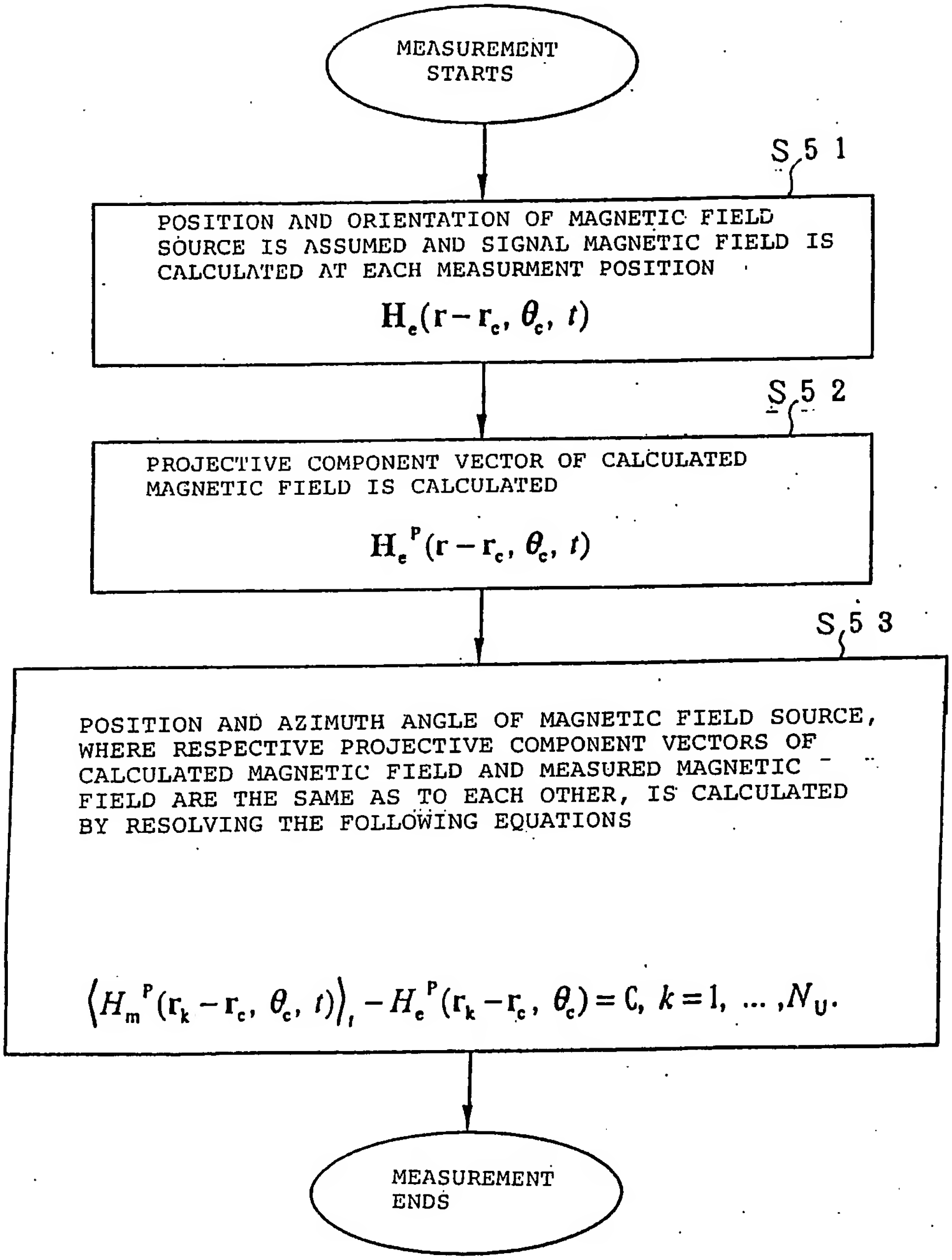

MEASUREMENT STARTS
S51
POSITION AND ORIENTATION OF MAGNETIC FIELD SOURCE IS ASSUMED AND SIGNAL MAGNETIC FIELD IS CALCULATED AT EACH MEASURMENT POSITION
$\mathbf{H}_e(\mathbf{r}-\mathbf{r}_c, \theta_c, t)$
S52
PROJECTIVE COMPONENT VECTOR OF CALCULATED MAGNETIC FIELD IS CALCULATED
$\mathbf{H}_e^{P}(\mathbf{r}-\mathbf{r}_c, \theta_c, t)$
S53
POSITION AND AZIMUTH ANGLE OF MAGNETIC FIELD SOURCE, WHERE RESPECTIVE PROJECTIVE COMPONENT VECTORS OF CALCULATED MAGNETIC FIELD AND MEASURED MAGNETIC FIELD ARE THE SAME AS TO EACH OTHER, IS CALCULATED BY RESOLVING THE FOLLOWING EQUATIONS
$\left\langle H_m^{P}(\mathbf{r}_k-\mathbf{r}_c, \theta_c, t)\right\rangle_t - H_e^{P}(\mathbf{r}_k-\mathbf{r}_c, \theta_c) = C,\ k=1, \ldots, N_U.$
MEASUREMENT ENDS

FIG.12

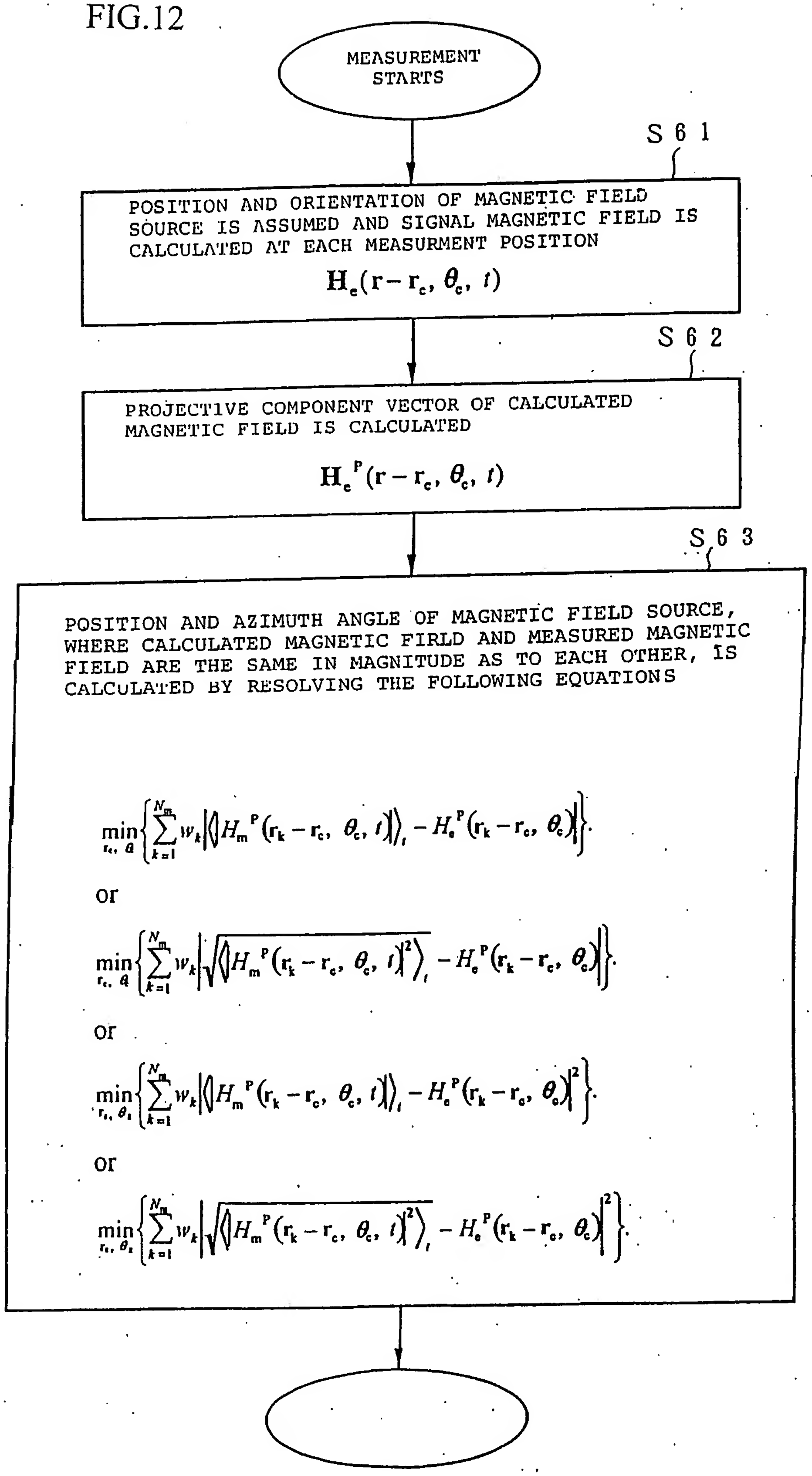

MEASUREMENT STARTS
S61
POSITION AND ORIENTATION OF MAGNETIC FIELD SOURCE IS ASSUMED AND SIGNAL MAGNETIC FIELD IS CALCULATED AT EACH MEASURMENT POSITION
$\mathbf{H}_e(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t)$
S62
PROJECTIVE COMPONENT VECTOR OF CALCULATED MAGNETIC FIELD IS CALCULATED
$\mathbf{H}_e^{P}(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t)$
S63
POSITION AND AZIMUTH ANGLE OF MAGNETIC FIELD SOURCE, WHERE CALCULATED MAGNETIC FIRLD AND MEASURED MAGNETIC FIELD ARE THE SAME IN MAGNITUDE AS TO EACH OTHER, IS CALCULATED BY RESOLVING THE FOLLOWING EQUATIONS
$$\min_{r_c,\,\theta_c}\left\{\sum_{k=1}^{N_m} w_k \left|\left\langle \left|H_m^{P}(r_k-r_c,\ \theta_c,\ t)\right|\right\rangle_t - H_e^{P}(r_k-r_c,\ \theta_c)\right|\right\}.$$
or
$$\min_{r_c,\,\theta_c}\left\{\sum_{k=1}^{N_m} w_k \left|\sqrt{\left\langle \left|H_m^{P}(r_k-r_c,\ \theta_c,\ t)\right|^2\right\rangle_t} - H_e^{P}(r_k-r_c,\ \theta_c)\right|\right\}.$$
or
$$\min_{r_c,\,\theta_c}\left\{\sum_{k=1}^{N_m} w_k \left|\left\langle \left|H_m^{P}(r_k-r_c,\ \theta_c,\ t)\right|\right\rangle_t - H_e^{P}(r_k-r_c,\ \theta_c)\right|^2\right\}.$$
or
$$\min_{r_c,\,\theta_c}\left\{\sum_{k=1}^{N_m} w_k \left|\sqrt{\left\langle \left|H_m^{P}(r_k-r_c,\ \theta_c,\ t)\right|^2\right\rangle_t} - H_e^{P}(r_k-r_c,\ \theta_c)\right|^2\right\}.$$

FIG.13

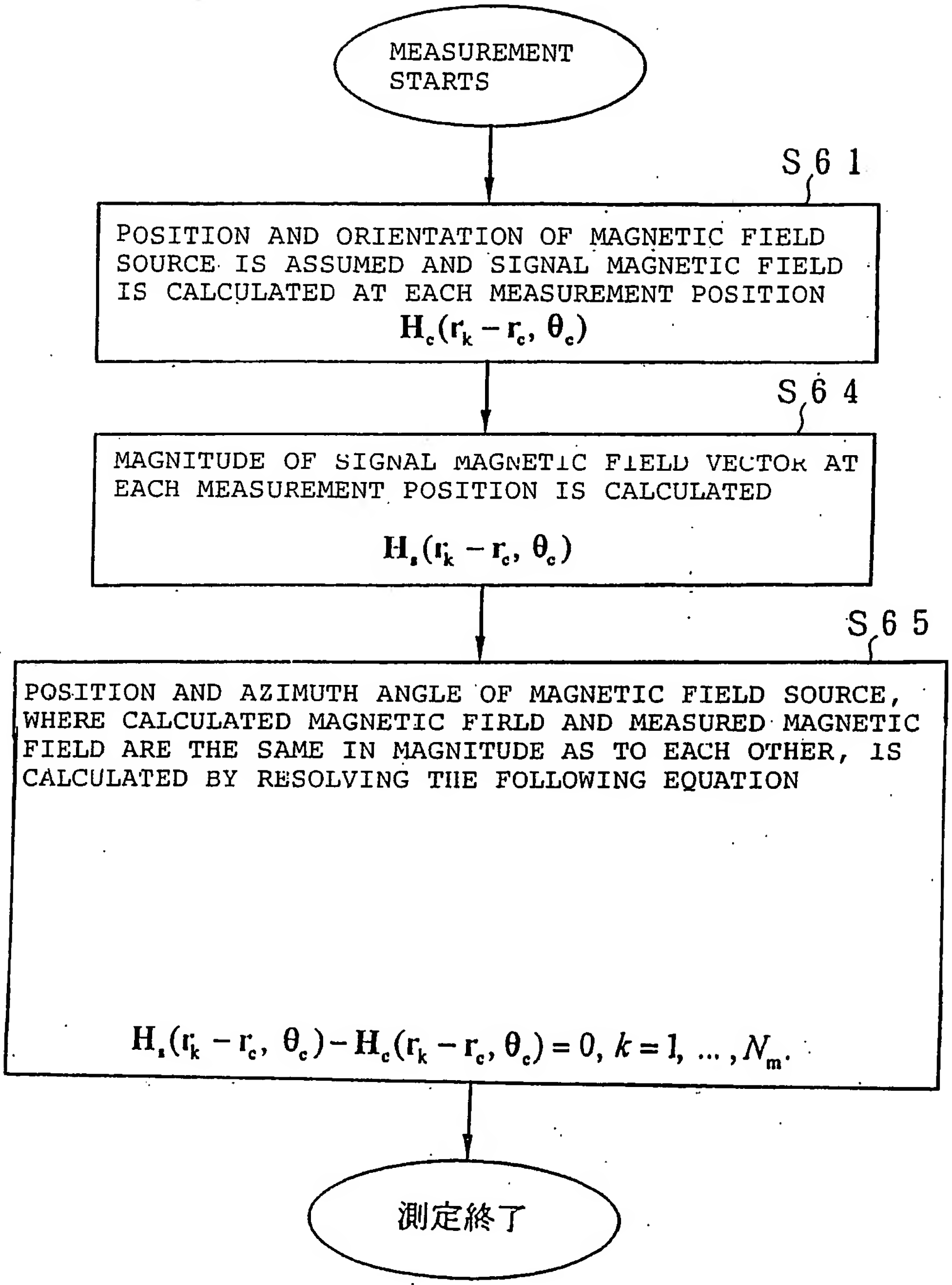

MEASUREMENT STARTS
S61
POSITION AND ORIENTATION OF MAGNETIC FIELD SOURCE IS ASSUMED AND SIGNAL MAGNETIC FIELD IS CALCULATED AT EACH MEASUREMENT POSITION
$\mathbf{H}_c(\mathbf{r}_k - \mathbf{r}_c, \theta_c)$
S64
MAGNITUDE OF SIGNAL MAGNETIC FIELD VECTOR AT EACH MEASUREMENT POSITION IS CALCULATED
$\mathbf{H}_s(\mathbf{r}_k - \mathbf{r}_c, \theta_c)$
S65
POSITION AND AZIMUTH ANGLE OF MAGNETIC FIELD SOURCE, WHERE CALCULATED MAGNETIC FIRLD AND MEASURED MAGNETIC FIELD ARE THE SAME IN MAGNITUDE AS TO EACH OTHER, IS CALCULATED BY RESOLVING THE FOLLOWING EQUATION
$\mathbf{H}_s(\mathbf{r}_k - \mathbf{r}_c, \theta_c) - \mathbf{H}_c(\mathbf{r}_k - \mathbf{r}_c, \theta_c) = 0,\ k = 1, \ldots, N_m.$
測定終了

FIG.14

MEASUREMENT STARTS

S61

POSITION AND ORIENTATION OF MAGNETIC FIELD SOURCE IS ASSUMED AND SIGNAL MAGNETIC FIELD IS CALCULATED AT EACH MEASURMENT POSITION

$$\mathbf{H}_o(\mathbf{r}_k - \mathbf{r}_o,\ \theta_o)$$

S64

PROJECTIVE COMPONENT VECTOR OF CALCULATED MAGNETIC FIELD IS CALCULATED

$$\mathbf{H}_s(\mathbf{r}_k - \mathbf{r}_o,\ \theta_o)$$

S66

POSITION AND AZIMUTH ANGLE OF MAGNETIC FIELD SOURCE, WHERE CALCULATED MAGNETIC FIRLD AND MEASURED MAGNETIC FIELD ARE THE SAME IN MAGNITUDE AS TO EACH OTHER, IS CALCULATED BY RESOLVING THE FOLLOWING EQUATIONS

$$\min_{r_c,\ \theta_c}\left\{\sum_{k=1}^{N_m} w_k \left|\mathbf{H}_s(\mathbf{r}_k - \mathbf{r}_o,\ \theta_o) - \mathbf{H}_o(\mathbf{r}_k - \mathbf{r}_o,\ \theta_o)\right|\right\}.$$

$$\min_{r_c,\ \theta_c}\left\{\sum_{k=1}^{N_m} w_k \left(\left\|\mathbf{H}_s(\mathbf{r}_k - \mathbf{r}_o,\ \theta_o)\right\| - \left\|\mathbf{H}_o(\mathbf{r}_k - \mathbf{r}_o,\ \theta_o)\right\|\right)^2\right\}.$$

$$\min_{r_c,\ \theta_s}\left\{\sum_{k=1}^{N_m} w_k \left|\mathbf{H}_s(\mathbf{r}_k - \mathbf{r}_o,\ \theta_o) - \mathbf{H}_o(\mathbf{r}_k - \mathbf{r}_o,\ \theta_o)\right|^2\right\}.$$

MEASUREMENT ENDS

FIG.15

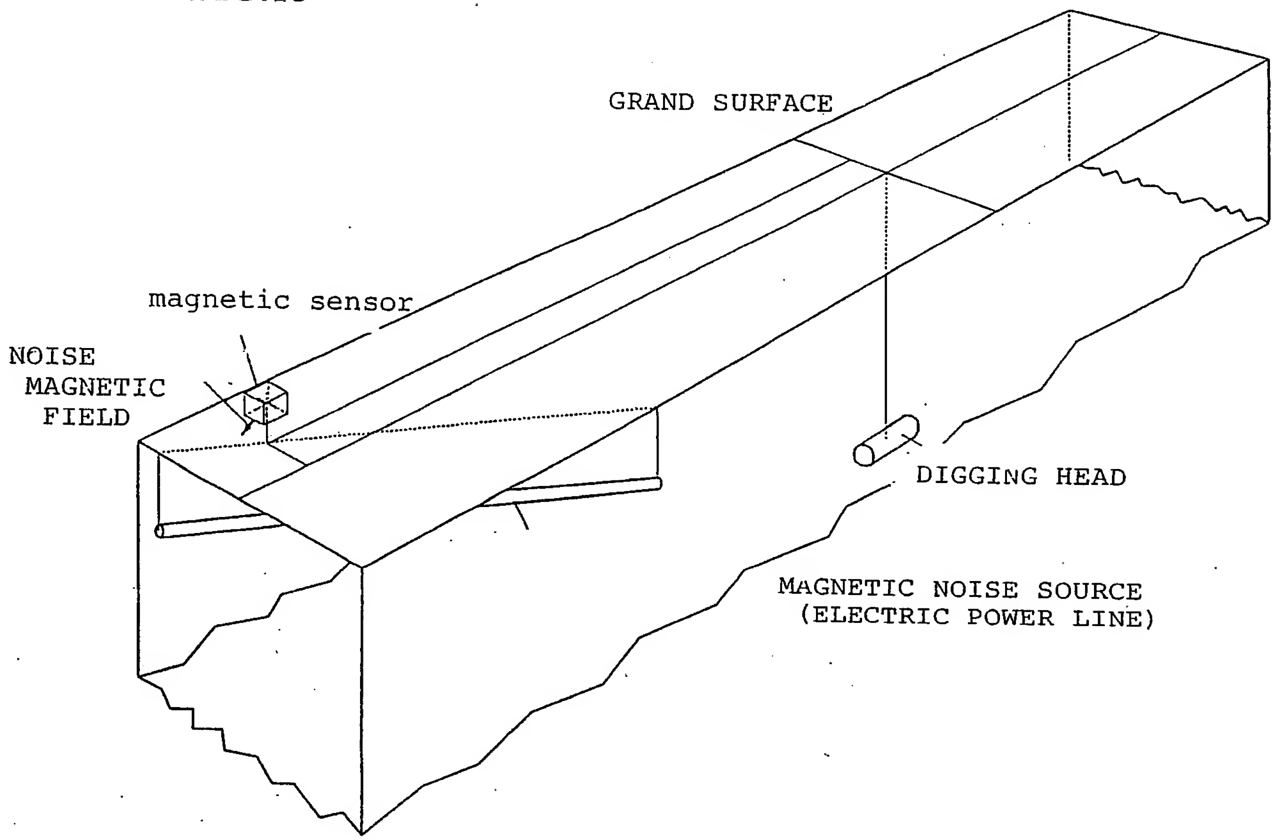

GRAND SURFACE
magnetic sensor
NOISE
MAGNETIC
FIELD
DIGGING HEAD
MAGNETIC NOISE SOURCE
(ELECTRIC POWER LINE)

FIG.16

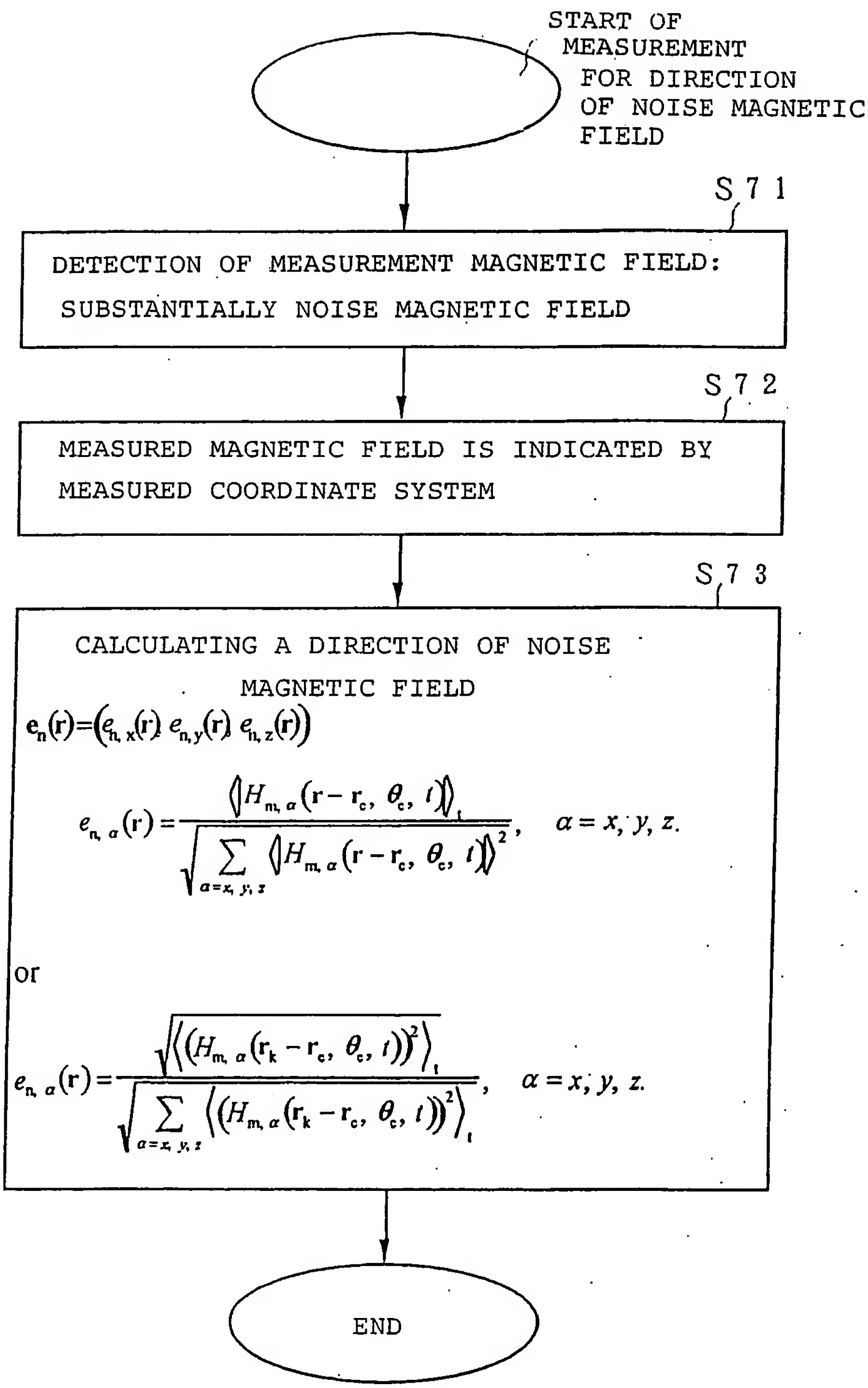

START OF MEASUREMENT FOR DIRECTION OF NOISE MAGNETIC FIELD
S71
DETECTION OF MEASUREMENT MAGNETIC FIELD:
SUBSTANTIALLY NOISE MAGNETIC FIELD
S72
MEASURED MAGNETIC FIELD IS INDICATED BY
MEASURED COORDINATE SYSTEM
S73
CALCULATING A DIRECTION OF NOISE
MAGNETIC FIELD
$\mathbf{e}_n(\mathbf{r})=\left(e_{n,x}(\mathbf{r}),\ e_{n,y}(\mathbf{r}),\ e_{n,z}(\mathbf{r})\right)$
$e_{n,\alpha}(\mathbf{r})=\dfrac{\left\langle H_{m,\alpha}(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t)\right\rangle_t}{\sqrt{\sum_{\alpha=x,y,z}\left\langle H_{m,\alpha}(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t)\right\rangle^2}},\quad \alpha=x,y,z.$
or
$e_{n,\alpha}(\mathbf{r})=\dfrac{\sqrt{\left\langle\left(H_{m,\alpha}(\mathbf{r}_k-\mathbf{r}_c,\ \theta_c,\ t)\right)^2\right\rangle_t}}{\sqrt{\sum_{\alpha=x,y,z}\left\langle\left(H_{m,\alpha}(\mathbf{r}_k-\mathbf{r}_c,\ \theta_c,\ t)\right)^2\right\rangle_t}},\quad \alpha=x,y,z.$
END

FIG.17

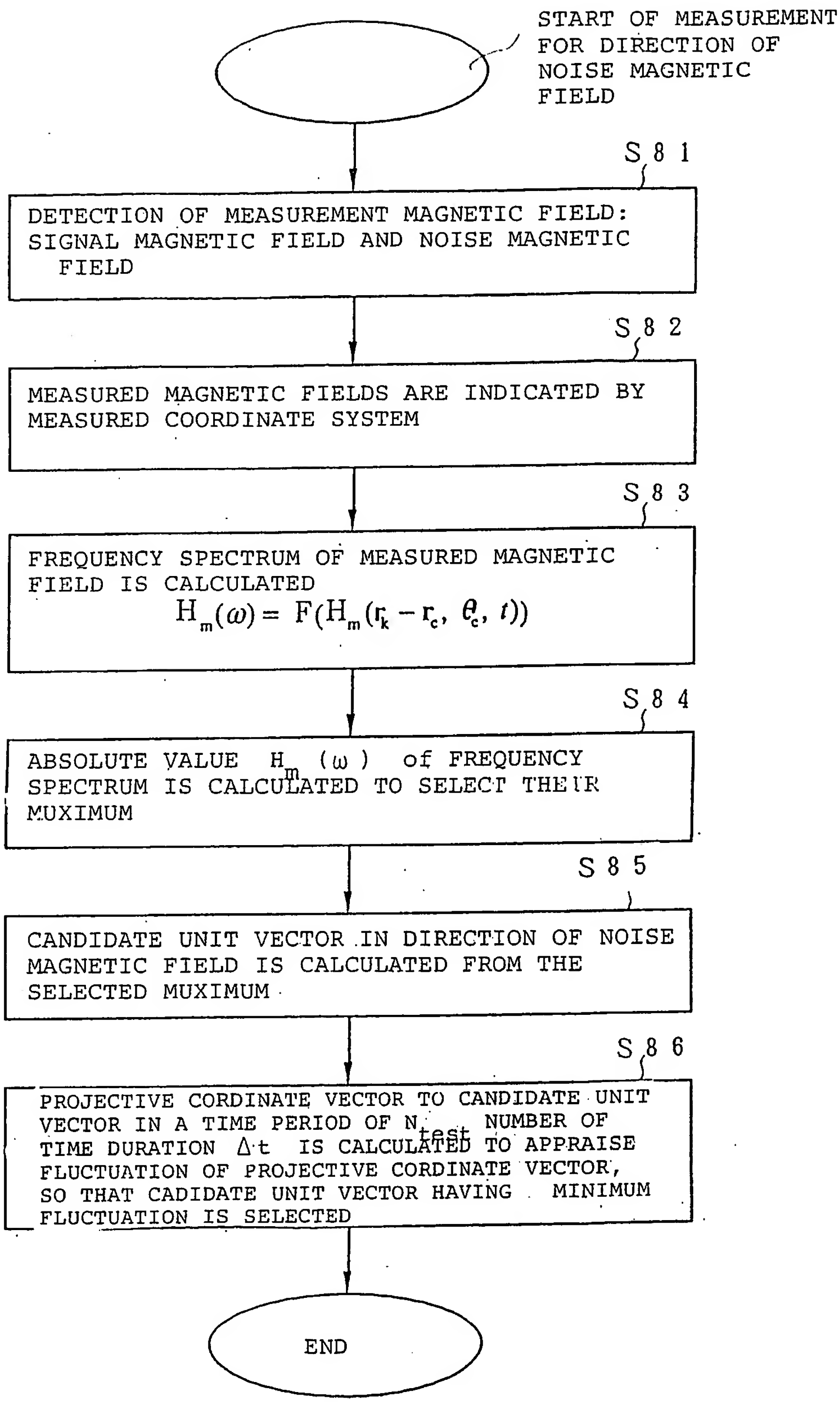

START OF MEASUREMENT FOR DIRECTION OF NOISE MAGNETIC FIELD
S81
DETECTION OF MEASUREMENT MAGNETIC FIELD: SIGNAL MAGNETIC FIELD AND NOISE MAGNETIC FIELD
S82
MEASURED MAGNETIC FIELDS ARE INDICATED BY MEASURED COORDINATE SYSTEM
S83
FREQUENCY SPECTRUM OF MEASURED MAGNETIC FIELD IS CALCULATED
$H_m(\omega) = F(H_m(r_k - r_c,\ \theta_c,\ t))$
S84
ABSOLUTE VALUE $H_m(\omega)$ of FREQUENCY SPECTRUM IS CALCULATED TO SELECT THEIR MUXIMUM
S85
CANDIDATE UNIT VECTOR IN DIRECTION OF NOISE MAGNETIC FIELD IS CALCULATED FROM THE SELECTED MUXIMUM
S86
PROJECTIVE CORDINATE VECTOR TO CANDIDATE UNIT VECTOR IN A TIME PERIOD OF N_{test} NUMBER OF TIME DURATION Δt IS CALCULATED TO APPRAISE FLUCTUATION OF PROJECTIVE CORDINATE VECTOR, SO THAT CADIDATE UNIT VECTOR HAVING MINIMUM FLUCTUATION IS SELECTED
END

FIG.18

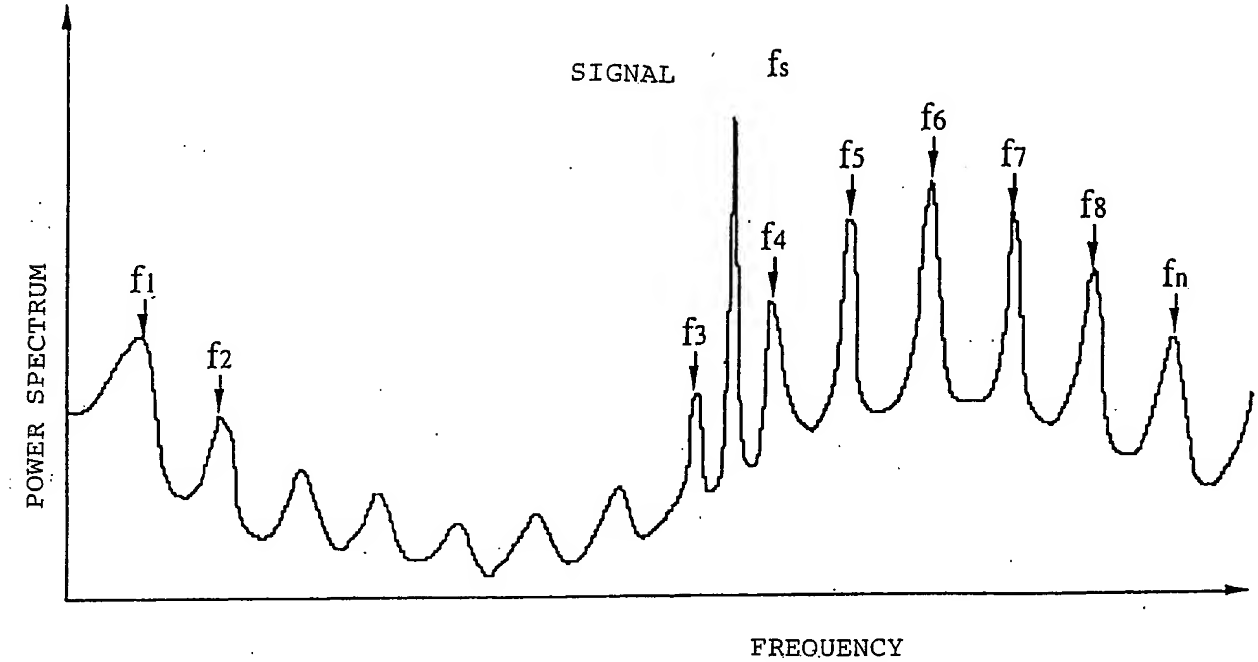

SIGNAL
f_s
f_1
f_2
f_3
f_4
f_5
f_6
f_7
f_8
f_n
POWER SPECTRUM
FREQUENCY

FIG.19

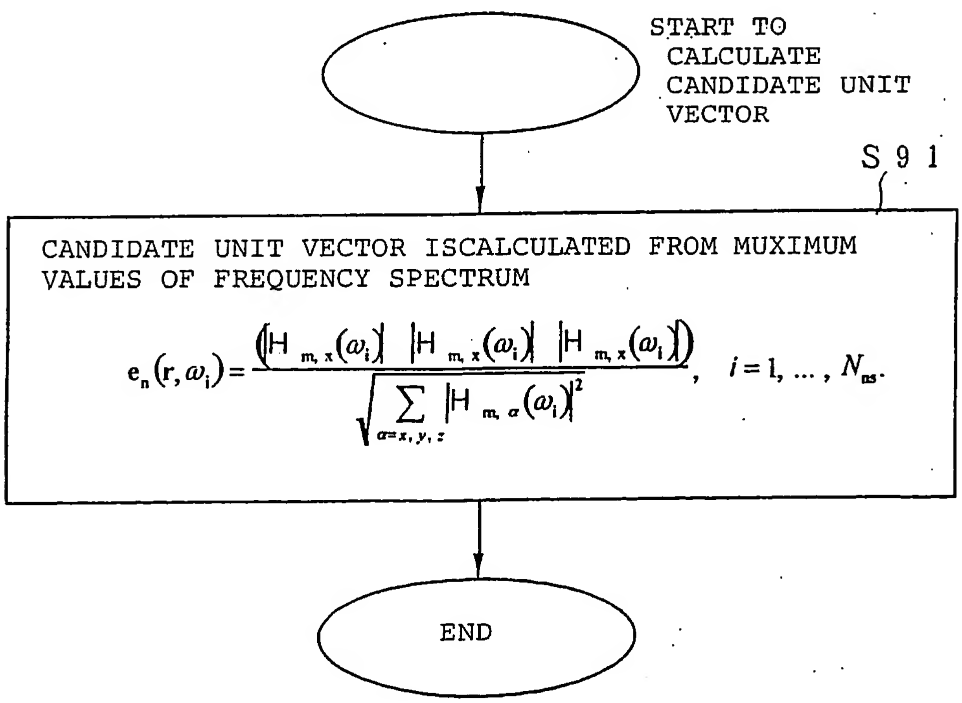

START TO CALCULATE CANDIDATE UNIT VECTOR
S 9 1
CANDIDATE UNIT VECTOR ISCALCULATED FROM MUXIMUM VALUES OF FREQUENCY SPECTRUM
$e_n(r,\omega_i)=\dfrac{\left(\left|H_{m,x}(\omega_i)\right|\ \left|H_{m,x}(\omega_i)\right|\ \left|H_{m,x}(\omega_i)\right|\right)}{\sqrt{\sum_{\alpha=x,y,z}\left|H_{m,\alpha}(\omega_i)\right|^2}},\quad i=1,\ \ldots,\ N_{ms}.$
END

FIG.20

START TO CALCULATE CANDIDATE UNIT VECTOR

S101

FROM MUXIMUM VALUES OF FREQUENCY SPECTRUM DERIVED BY FILTERING AT CORRESPONDING CENTER FREQUENCY, CORRESPONDING FREQUENCY COMPONENTS IN THE MEASURED MAGNETIC FIELD

S102

FROM FREQUENCY COMPONENTS DERIVED BY FILTERING, CANDIDATE UNIT VECTOR

$$\mathbf{e}_n(\mathbf{r}) = \left(e_{n,x}(\mathbf{r}),\ e_{n,y}(\mathbf{r}),\ e_{n,z}(\mathbf{r})\right)$$

ARE CALCULATED BY ANY OF FOLLOWING PROCEDURES

$$e_{n,\alpha}(\mathbf{r},\ \omega_i) = \frac{\left\langle \left| H_{m,\alpha}(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ \omega_i,\ t) \right| \right\rangle_t}{\sqrt{\sum_{\alpha=x,y,z} \left\langle \left| H_{m,\alpha}(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ \omega_i,\ t) \right| \right\rangle^2}},$$

$$\alpha = x,\ y,\ z;\ i = 1,\ \ldots,\ N_{ns}.$$

OR

$$e_{n,\alpha}(\mathbf{r},\ \omega_i) = \frac{\sqrt{\left\langle \left(H_{m,x}(\mathbf{r}_k-\mathbf{r}_c,\ \theta_c,\ \omega_i,\ t) \right)^2 \right\rangle_t}}{\sqrt{\sum_{\alpha=x,y,z} \left\langle \left(H_{m,\alpha}(\mathbf{r}_k-\mathbf{r}_c,\ \theta_c,\ \omega_i,\ t) \right)^2 \right\rangle_t}},$$

$$\alpha = x,\ y,\ z;\ i = 1,\ \ldots,\ N_{ns}.$$

END

FIG.21

START TO CALCULATE DIRECTION OF NOISE MAGNETIC FIELD

S111

PROJECTIVE CORDINATE VECTOR TO CANDIDATE UNIT VECTOR IN A TIME PERIOD OF N_{test} NUMBER OF TIME DURATION Δt IS CALCULATED

$$\mathbf{H}_m{}^P(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ \omega_i,\ t)=\mathbf{H}_m(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t)-(\mathbf{H}_m(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t)\cdot\mathbf{e}_n(\mathbf{r},\ \omega_i))\mathbf{e}_n(\mathbf{r},\ \omega_i),\ i=1,\ \ldots,\ N_{ns}.$$

S112

VARIATION OF PROJECTIVE COMPONENT

$\nu_{eval,\,k}(\omega_i),\ k=1,\ \ldots,\ N_{test}$

$$\nu_{eval,\,k}(\omega_i)=\left\langle\left|H_{m,\,q}{}^P(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ \omega_i,\ t)\right|\right\rangle_{T_{t,k}},\ q=1,\ 2;\ k=1,\ \ldots,\ N_{test};\ i=1,\ \ldots,\ N_{ns}.$$

OR

$$\nu_{eval,\,k}(\omega_i)=\left\langle\left|\mathbf{H}_m{}^P(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ \omega_i,\ t)\right|\right\rangle_{T_{t,k}},\ k=1,\ \ldots,\ N_{test};\ i=1,\ \ldots,\ N_{ns}.$$

OR

$$\nu_{eval,\,k}(\omega_i)=\left\langle(H_{m,\,q}{}^P(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ \omega_i,\ t))^2\right\rangle_{T_{t,k}},$$
$$q=1,\ 2;\ k=1,\ \ldots,\ N_{test};\ i=1,\ \ldots,\ N_{ns}.$$

OR

$$\nu_{eval,\,k}(\omega_i)=\sqrt{\left\langle(H_{m,\,q}{}^P(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ \omega_i,\ t))^2\right\rangle_{T_{t,k}}},$$
$$q=1,\ 2;\ k=1,\ \ldots,\ N_{test};\ i=1,\ \ldots,\ N_{ns}.$$

S113

CANDIDATE UNIT VECTOR HAVING MINIMUM ONE OF FOLLOWING VARIANCE IS SELECTED AS DIRECTION OF NOUSE MAGNETIC FIELD

$$\mathrm{var}(\omega_i)=\frac{\sqrt{\mathrm{mean}_k((\nu_{eval,\,k}(\omega_i)-\mathrm{mean}_k(\nu_{eval,\,k}(\omega_i)))^2)}}{\mathrm{mean}_k(\nu_{eval,\,k}(\omega_i))},i=1,\ \ldots,\ N_{ns}.$$

END

FIG.22

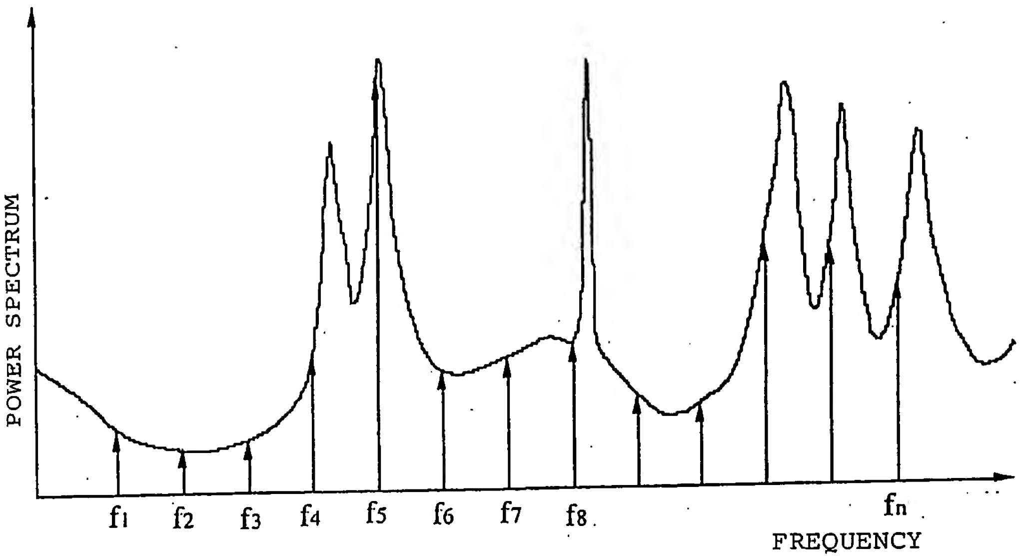


FIG.23

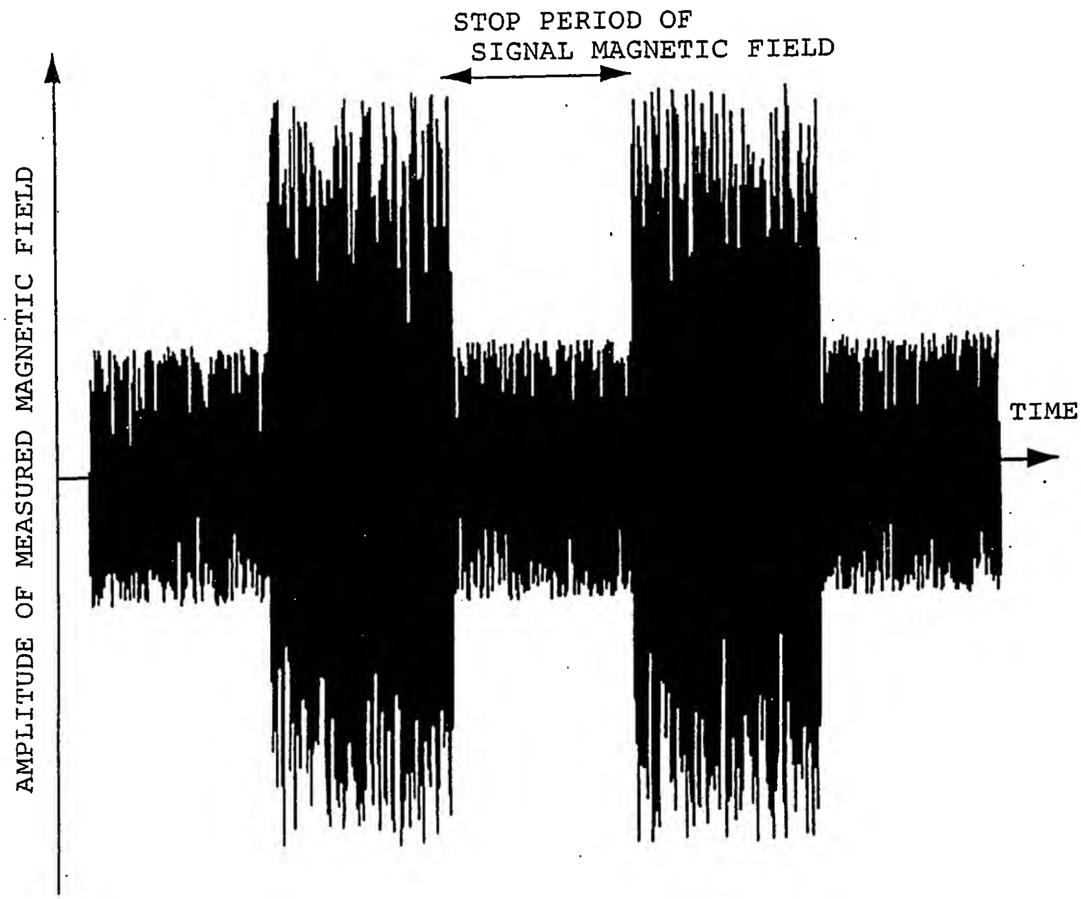

STOP PERIOD OF
SIGNAL MAGNETIC FIELD
AMPLITUDE OF MEASURED MAGNETIC FIELD
TIME

FIG.24

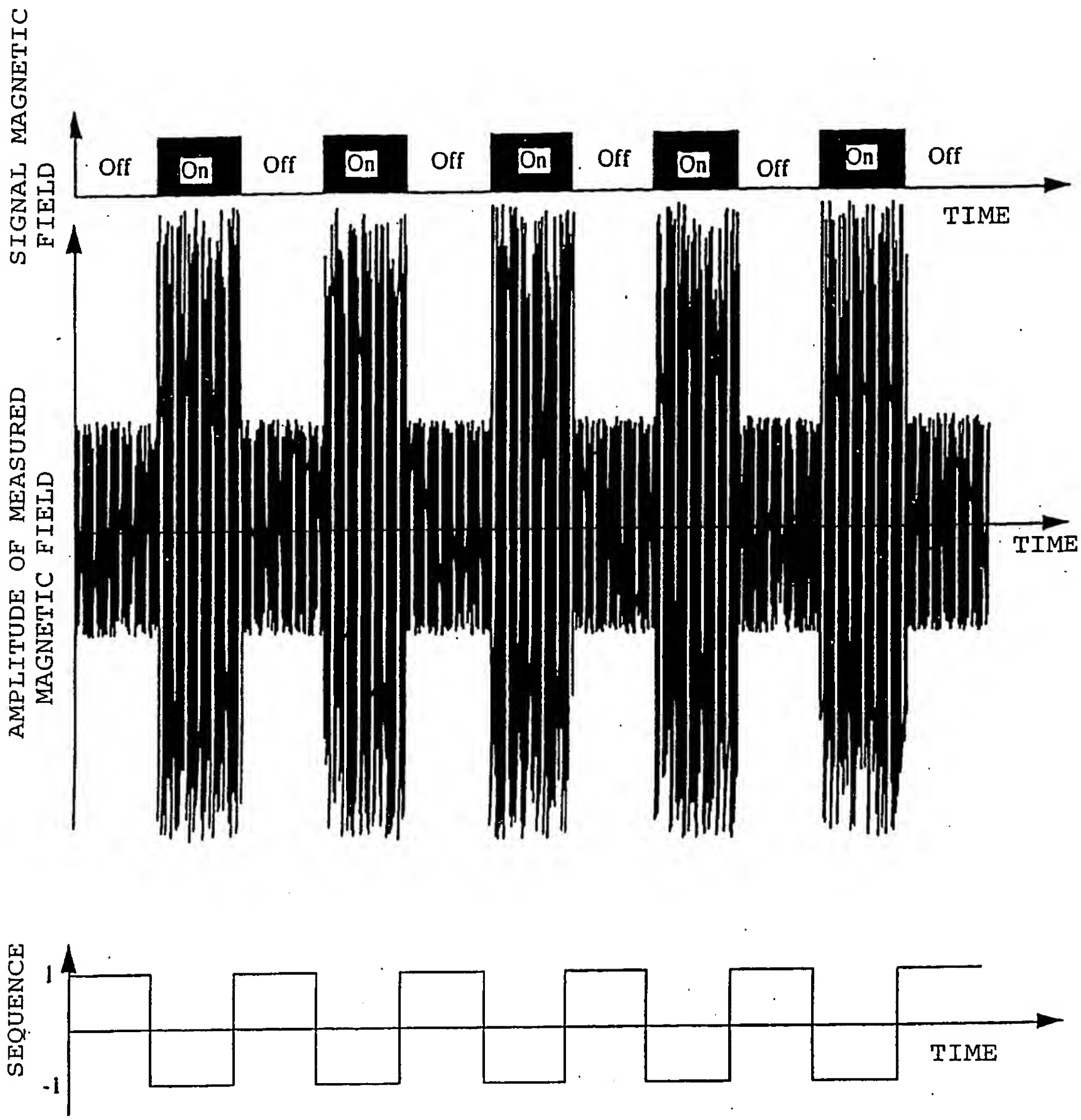

SIGNAL MAGNETIC FIELD
Off
On
Off
On
Off
On
Off
On
Off
On
Off
TIME
AMPLITUDE OF MEASURED MAGNETIC FIELD
TIME
SEQUENCE
1
-1
TIME

FIG.25

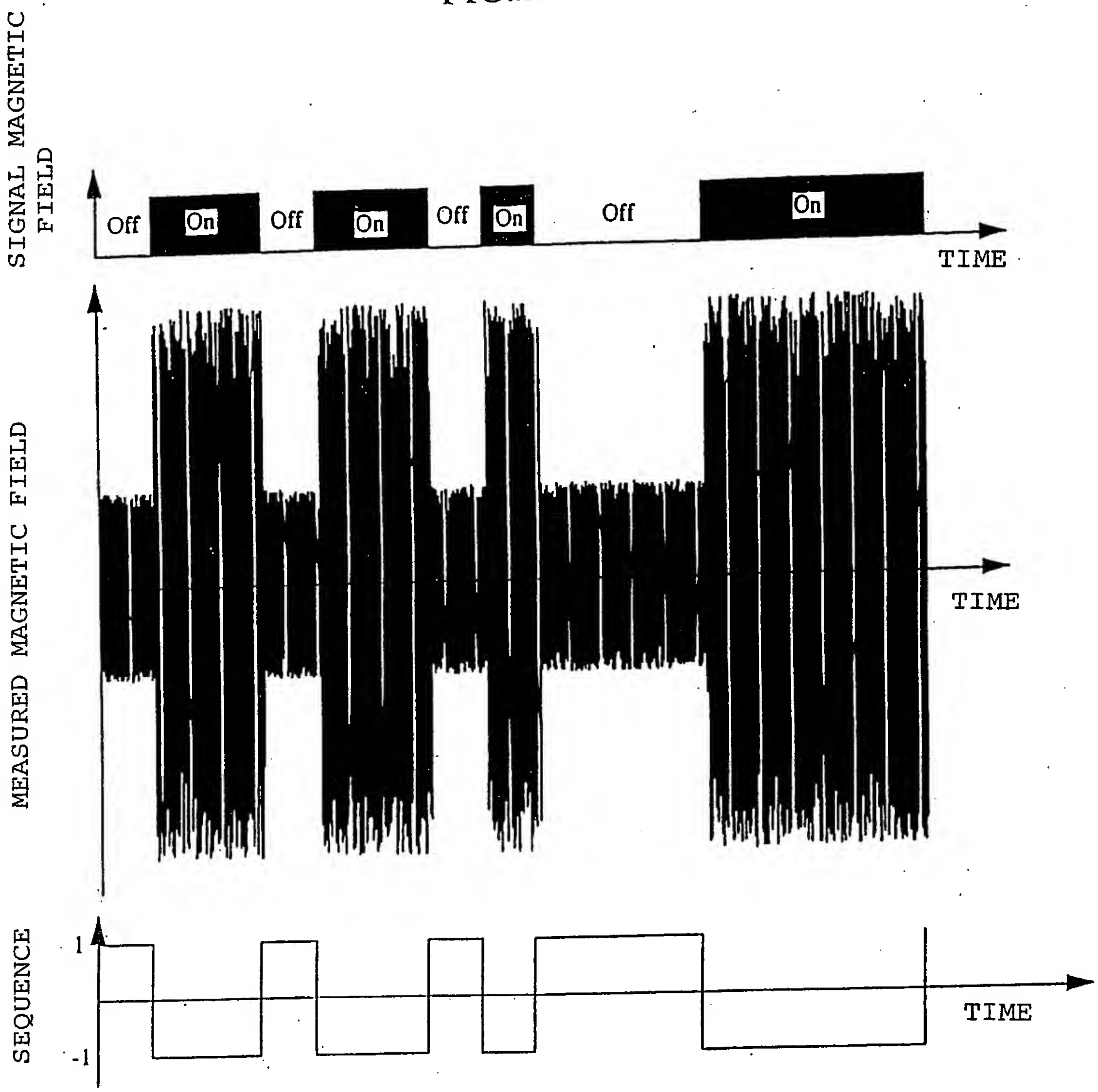

SIGNAL MAGNETIC FIELD
Off
On
Off
On
Off
On
Off
On
TIME
MEASURED MAGNETIC FIELD
TIME
SEQUENCE
1
-1
TIME

FIG.26

START OF MEASUREMENT FOR DIRECTION OF NOISE MAGNETIC FIELD

S121

DETECTION OF MEASUREMENT MAGNETIC FIELD: SIGNAL MAGNETIC FIELD AND NOISE MAGNETIC FIELD

S122

MEASURED MAGNETIC FIELDS ARE INDICATED BY MEASURED COORDINATE SYSTEM

S123

CORRELATION BETWEEN SEQUENCE AND AND MEASURED MAGNETIC FIELD IS CALCULATED

$$R(\tau)=\int_{t_k}^{t_k+N_T T_{\text{period}}} \left|\mathbf{H}_m(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t)\right| s(t-\tau)dt.$$

OR

$$R(\tau)=\int_{t_k}^{t_k+N_T T_{\text{period}}} \sqrt{\left(\mathbf{H}_m(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t)\right)^2}\, s(t-\tau)dt.$$

OR

$$R_\alpha(\tau)=\int_{t_k}^{t_k+N_T T_{\text{period}}} \left|H_{m,\alpha}(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t)\right| s(t-\tau)dt,\ \alpha=x,y,z.$$

OR

$$R_\alpha(\tau)=\int_{t_k}^{t_k+N_T T_{\text{period}}} \sqrt{\left(H_{m,\alpha}(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t)\right)^2}\, s(t-\tau)dt,\ \alpha=x,y,z.$$

S124

TIME $\tau = t_{\text{sync}}$ WHERE CORRELATION $R(\tau)$ or $R_\alpha(\tau)$ BECOMES MAXIMUM IS OBTAINED

S125

TIME PERIOD WHERE SIGNAL MAGNETIC FIELD IS STOPPED IS IDENTIFIED BY SEQUENCE $s(t-t_{\text{sync}})$

S126

TIME PERIOD WHERE SIGNAL MAGNETIC FIELD IS STOPPED IS OBTAINED AS DIRECTION OF NOISE MAGNETIC FIELD

END

FIG.27

START OF MEASUREMENT FOR DIRECTION OF NOISE MAGNETIC FIELD

S131

DETECTION OF MEASUREMENT MAGNETIC FIELD: SIGNAL MAGNETIC FIELD AND NOISE MAGNETIC FIELD

S132

MEASURED MAGNETIC FIELDS ARE INDICATED BY MEASURED COORDINATE SYSTEM

S133

CORRELATION BETWEEN SEQUENCE AND AND MEASURED MAGNETIC FIELD IS CALCULATED

$$R(\tau)=\int_{t_k}^{t_k+N_T T_{period}} \left|\mathbf{H}_m(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t)\right| s(t-\tau)dt.$$

OR

$$R(\tau)=\int_{t_k}^{t_k+N_T T_{period}} \sqrt{\left(\mathbf{H}_m(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t)\right)^2}\, s(t-\tau)dt.$$

OR

$$R_\alpha(\tau)=\int_{t_k}^{t_k+N_T T_{period}} \left|H_{m,\alpha}(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t)\right| s(t-\tau)dt,\ \alpha=x,y,z.$$

OR

$$R_\alpha(\tau)=\int_{t_k}^{t_k+N_T T_{period}} \sqrt{\left(H_{m,\alpha}(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t)\right)^2}\, s(t-\tau)dt,\ \alpha=x,y,z.$$

S134

TIME $\tau = t_{sync,k},\ k=1,\ldots,N_{sync}$ WHERE CORRELATION $R(\tau)$ or $R_\alpha(\tau)$ BECOMES MAXIMUM IS OBTAINED

S135

MINIMUM (k=1) IS SUBSTRACTED FROM REMAINDER IN START TIMES OF SEQUENCE

$$\Delta t_{sync,k} = t_{sync,k} - t_{sync,1},\quad k=2,\ \ldots,\ N_{sync}.$$

S136

INTEGER MULTIPLE OF TIME UNIT Δt_{unit} NEAREST TO TIME DIFFERENCE $\Delta t_{sync,k}$ IS SUBSTRACTED TO OBTAIN AVERAGE VALUE

$$\delta t_{sync} = \frac{\sum_{k=1}^{N_{sync}}\left(\Delta t_{sync,k} - M_{sync,k}\Delta t_{unit}\right)}{N_{sync}-1}.$$

S137

STOP TIME PERIOD OF SIGNAL MAGNETIC FIELD IS IDENTIFIED BY SEQUENCE WHERE START TIME IS SELECTED

$$t_{sync} = t_{sync,1} + \delta t_{sync}$$

S138

TIME PERIOD WHERE SIGNAL MAGNETIC FIELD IS STOPPED IS OBTAINED AS DIRECTION OF NOISE MAGNETIC FIELD

END

FIG.28

START OF MEASUREMENT FOR DIRECTION OF NOISE MAGNETIC FIELD

S141

DETECTION OF MEASUREMENT MAGNETIC FIELD: SIGNAL MAGNETIC FIELD AND NOISE MAGNETIC FIELD

S142

MEASURED MAGNETIC FIELDS ARE INDICATED BY MEASURED COORDINATE SYSTEM

S143

CORRELATION BETWEEN SEQUENCE AND AND MEASURED MAGNETIC FIELD IS CALCULATED

$$R_\alpha(t_k) = \int_{t_k}^{t_k + T_{period}} \left| H_{m,\alpha}(\mathbf{r} - \mathbf{r}_c,\ \theta_c,\ t) \right| s(t - t_k)\,dt,$$
$$k = 1, \ldots, N_{div};\ \alpha = x, y, z.$$

OR

$$R_\alpha(t_k) = \int_{t_k}^{t_k + T_{period}} \sqrt{\left(H_{m,\alpha}(\mathbf{r} - \mathbf{r}_c,\ \theta_c,\ t)\right)^2}\, s(t - t_k)\,dt,$$

BUT

$$k = 1, \ldots, N_{div};\ \alpha = x, y, z.$$

$$t_k = t_0 + k \cdot T_{div}, \quad k = 1, \ \ldots, N_{div}.$$
$$S_{mp}(t) = S\left(t + T_{period}\right)$$
$$S_{mp}(t) = s(t), \quad 0 \le t < T_{period}.$$

S144

PROJECTIVE COMPONENT VECTOR OF MEASURED MAGNETIC FIELD TO PLANE PERPENDICULAR TO VECTOR

$$\mathbf{e}_n(t_k) = \left(R_x(t_k)\ R_y(t_k)\ R_z(t_k)\right)\ k = 1, \ \ldots, N_{div}.$$

OF CORRELATION $R_\alpha(t_k),\ k = 1, \ldots, N_{div};\ \alpha = x, y, z.$

IS OBTAINED

$$\mathbf{H}_m^P(\mathbf{r} - \mathbf{r}_c,\ \theta_c,\ t_k,\ t),\ k = 1, \ldots, N_{div}.$$

S145a

t_k IS CALCULATED SO THAT VARIANCE

$$\mathrm{var}(t_k) = \frac{\sqrt{\left\langle \left(\left|\mathbf{H}_m^P(\mathbf{r} - \mathbf{r}_c,\ \theta_c,\ t_k,\ t)\right| - \left\langle \left|\mathbf{H}_m^P(\mathbf{r} - \mathbf{r}_c,\ \theta_c,\ t_k,\ t)\right| \right\rangle_t \right)^2 \right\rangle_t}}{\left\langle \left|\mathbf{H}_m^P(\mathbf{r} - \mathbf{r}_c,\ \theta_c,\ t_k,\ t)\right| \right\rangle_t},$$
$$k = 1, \ \ldots, N_{div}.$$

IS MINIMUM OR LESS THAN DETERMINED VALUE

$$\mathbf{e}_n(t_k) = \left(R_x(t_k)\ R_y(t_k)\ R_z(t_k)\right)\ k = 1, \ \ldots, N_{div}.$$

CORRESPONDING TO t_k IS SELECTED AS DIRECTION OF NOISE MAGNETIC FIELD

END

FIG.29

START O EASUREMENT FOR DIRECTION OF NOISE MAGNETIC FIELD

S141

DETECTION OF MEASUREMENT MAGNETIC FIELD: SIGNAL MAGNETIC FIELD AND NOISE MAGNETIC FIELD

S142

MEASURED MAGNETIC FIELDS ARE INDICATED BY MEASURED COORDINATE SYSTEM

S143

CORRELATION BETWEEN SEQUENCE AND AND MEASURED MAGNETIC FIELD IS CALCULATED

$$R_\alpha(t_k) = \int_{t_k}^{t_k+T_{period}} \left| H_{m,\alpha}(\mathrm{r}-\mathrm{r}_c,\ \theta_c,\ t) \right| s(t-t_k)dt,$$

$$k = 1, \ldots, N_{div};\ \alpha = x,y,z.$$

OR

$$R_\alpha(t_k) = \int_{t_k}^{t_k+T_{period}} \sqrt{\left(H_{m,\alpha}(\mathrm{r}-\mathrm{r}_c,\ \theta_c,\ t)\right)^2}\, s(t-t_k)dt,$$

BUT

$$k = 1, \ldots, N_{div};\ \alpha = x,y,z.$$

$$t_k = t_0 + k \cdot T_{div},\quad k = 1,\ \ldots,\ N_{div}.$$

$$S_{mp}(t) = S(t + T_{period})$$

$$S_{mp}(t) = s(t),\ \ 0 \le t < T_{period}.$$

S144

PROJECTIVE COMPONENT VECTOR OF MEASURED MAGNETIC FIELD TO PLANE PERPENDICULAR TO VECTOR

$$\mathrm{e}_n(t_k) = \left(R_x(t_k),\ R_y(t_k),\ R_z(t_k)\right),\ k=1,\ \ldots,\ N_{div}.$$

OF CORRELATION $R_\alpha(t_k),\ k=1,\ \ldots,\ N_{div};\ \alpha = x,y,z.$

IS OBTAINED

$$\mathrm{H}_m^{\,P}(\mathrm{r}-\mathrm{r}_c,\ \theta_c,\ t_k,\ t),\ k=1,\ \ldots,\ N_{div}.$$

S145b

t_k IS CALCULATED SO THAT FOR VARIANCE

$$\mathrm{var}_\alpha(t_k) = \frac{\sqrt{\left\langle \left(H_{m,\alpha}^{\ P}(\mathrm{r}-\mathrm{r}_c,\ \theta_c,\ t_k,\ t) - \left\langle H_{m,\alpha}^{\ P}(\mathrm{r}-\mathrm{r}_c,\ \theta_c,\ t_k,\ t)\right\rangle_t \right)^2 \right\rangle_t}}{\left\langle \left|\mathrm{H}_m^{\,P}(\mathrm{r}-\mathrm{r}_c,\ \theta_c,\ t_k,\ t)\right| \right\rangle_t};$$

$$\alpha = x,\ y,\ z,\ k=1,\ \ldots,\ N_{div}.\ -1,\ \ldots,\ N_{div}.,$$

$$\sum_{\alpha=x,y,z} \mathrm{var}_\alpha(t_k)$$

OR

$$\sqrt{\sum_{\alpha=x,y,z} \left(\mathrm{var}_\alpha(t_k)\right)^2}.$$

IS MINIMUM OR LESS THAN DETERMINED VALUE

$$\mathrm{e}_n(t_k) = \left(R_x(t_k),\ R_y(t_k),\ R_z(t_k)\right),\ k=1,\ \ldots,\ N_{div}.$$

CORRESPONDING TO t_k IS SELECTED AS DIRECTION OF NOISE MAGNETIC FIELD

END

FIG.30

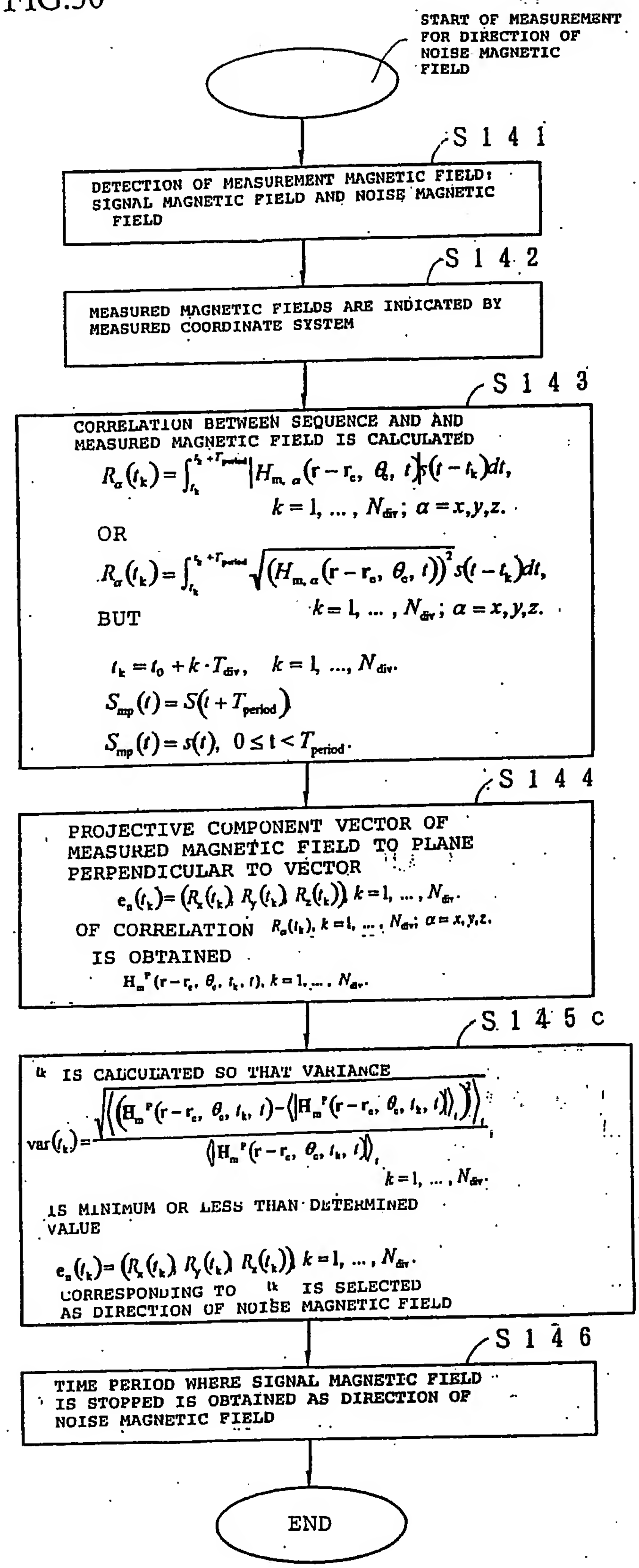

START OF MEASUREMENT FOR DIRECTION OF NOISE MAGNETIC FIELD
S141
DETECTION OF MEASUREMENT MAGNETIC FIELD: SIGNAL MAGNETIC FIELD AND NOISE MAGNETIC FIELD
S142
MEASURED MAGNETIC FIELDS ARE INDICATED BY MEASURED COORDINATE SYSTEM
S143
CORRELATION BETWEEN SEQUENCE AND AND MEASURED MAGNETIC FIELD IS CALCULATED
$R_\alpha(t_k)=\int_{t_k}^{t_k+T_{period}}\left|H_{m,\alpha}(r-r_c,\ \theta_c,\ t)\right|s(t-t_k)dt,$
$k=1,\ \ldots,\ N_{div};\ \alpha=x,y,z.$
OR
$R_\alpha(t_k)=\int_{t_k}^{t_k+T_{period}}\sqrt{\left(H_{m,\alpha}(r-r_c,\ \theta_c,\ t)\right)^2}\,s(t-t_k)dt,$
$k=1,\ \ldots,\ N_{div};\ \alpha=x,y,z.$
BUT
$t_k=t_0+k\cdot T_{div},\quad k=1,\ \ldots,\ N_{div}.$
$S_{mp}(t)=S(t+T_{period})$
$S_{mp}(t)=s(t),\ 0\le t<T_{period}.$
S144
PROJECTIVE COMPONENT VECTOR OF MEASURED MAGNETIC FIELD TO PLANE PERPENDICULAR TO VECTOR
$e_n(t_k)=\left(R_x(t_k),\ R_y(t_k),\ R_z(t_k)\right),\ k=1,\ \ldots,\ N_{div}.$
OF CORRELATION $R_\alpha(t_k),\ k=1,\ \ldots,\ N_{div};\ \alpha=x,y,z.$
IS OBTAINED
$H_m^P(r-r_c,\ \theta_c,\ t_k,\ t),\ k=1,\ \ldots,\ N_{div}.$
S145c
t_k IS CALCULATED SO THAT VARIANCE
$var(t_k)=\dfrac{\sqrt{\left\langle\left(H_m^P(r-r_c,\ \theta_c,\ t_k,\ t)-\left\langle\left|H_m^P(r-r_c,\ \theta_c,\ t_k,\ t)\right|\right\rangle_t\right)^2\right\rangle_t}}{\left\langle\left|H_m^P(r-r_c,\ \theta_c,\ t_k,\ t)\right|\right\rangle_t},$
$k=1,\ \ldots,\ N_{div}.$
IS MINIMUM OR LESS THAN DETERMINED VALUE
$e_n(t_k)=\left(R_x(t_k),\ R_y(t_k),\ R_z(t_k)\right),\ k=1,\ \ldots,\ N_{div}.$
CORRESPONDING TO t_k IS SELECTED AS DIRECTION OF NOISE MAGNETIC FIELD
S146
TIME PERIOD WHERE SIGNAL MAGNETIC FIELD IS STOPPED IS OBTAINED AS DIRECTION OF NOISE MAGNETIC FIELD
END

FIG.31

START OF MEASUREMENT FOR DIRECTION OF NOISE MAGNETIC FIELD

S141

DETECTION OF MEASUREMENT MAGNETIC FIELD: SIGNAL MAGNETIC FIELD AND NOISE MAGNETIC FIELD

S142

MEASURED MAGNETIC FIELDS ARE INDICATED BY MEASURED COORDINATE SYSTEM

S143

CORRELATION BETWEEN SEQUENCE AND AND MEASURED MAGNETIC FIELD IS CALCULATED

$$R_\alpha(t_k) = \int_{t_k}^{t_k + T_{period}} \left| H_{m,\alpha}(\mathrm{r} - \mathrm{r}_c,\ \theta_c,\ t) \right| s(t - t_k)\,dt,$$

OR $\quad k = 1, \ldots, N_{div};\ \alpha = x, y, z.$

$$R_\alpha(t_k) = \int_{t_k}^{t_k + T_{period}} \sqrt{\left(H_{m,\alpha}(\mathrm{r} - \mathrm{r}_c,\ \theta_c,\ t)\right)^2}\, s(t - t_k)\,dt,$$

$$k = 1, \ldots, N_{div};\ \alpha = x, y, z.$$

BUT

$$t_k = t_0 + k \cdot T_{div}, \quad k = 1, \ldots, N_{div}.$$

$$S_{mp}(t) = S(t + T_{period})$$

$$S_{mp}(t) = s(t),\ 0 \le t < T_{period}.$$

S144

PROJECTIVE COMPONENT VECTOR OF MEASURED MAGNETIC FIELD TO PLANE PERPENDICULAR TO VECTOR

$$\mathrm{e}_\alpha(t_k) = \left(R_x(t_k)\ R_y(t_k)\ R_z(t_k)\right)\ k = 1, \ldots, N_{div}.$$

OF CORRELATION $R_\alpha(t_k),\ k = 1, \ldots, N_{div};\ \alpha = x, y, z.$

IS OBTAINED

$$\mathrm{H}_m{}^P(\mathrm{r} - \mathrm{r}_c,\ \theta_c,\ t_k,\ t),\ k = 1, \ldots, N_{div}.$$

S145d

t_k IS CALCULATED SO THAT FOR VARIANCE

$$\mathrm{var}_\alpha(t_k) = \frac{\sqrt{\left\langle \left(H_{m,\alpha}{}^P(\mathrm{r} - \mathrm{r}_c,\ \theta_c,\ t_k,\ t) - \left\langle \left| H_{m,\alpha}{}^P(\mathrm{r} - \mathrm{r}_c,\ \theta_c,\ t_k,\ t) \right| \right\rangle_t \right)^2 \right\rangle_t}}{\left\langle \left| \mathrm{H}_m{}^P(\mathrm{r} - \mathrm{r}_c,\ \theta_c,\ t_k,\ t) \right| \right\rangle_t},$$

$$\alpha = x, y, z,\ k = 1, \ldots, N_{div}.\ 1, \ldots, N_{div}.,$$

$$\sum_{\alpha = x, y, z} \mathrm{var}_\alpha(t_k)$$

OR

$$\sqrt{\sum_{\alpha = x, y, z} \left(\mathrm{var}_\alpha(t_k)\right)^2}.$$

IS MINIMUM OR LESS THAN DETERMINED VALUE

$$\mathrm{e}_\alpha(t_k) = \left(R_x(t_k)\ R_y(t_k)\ R_z(t_k)\right)\ k = 1, \ldots, N_{div}.$$

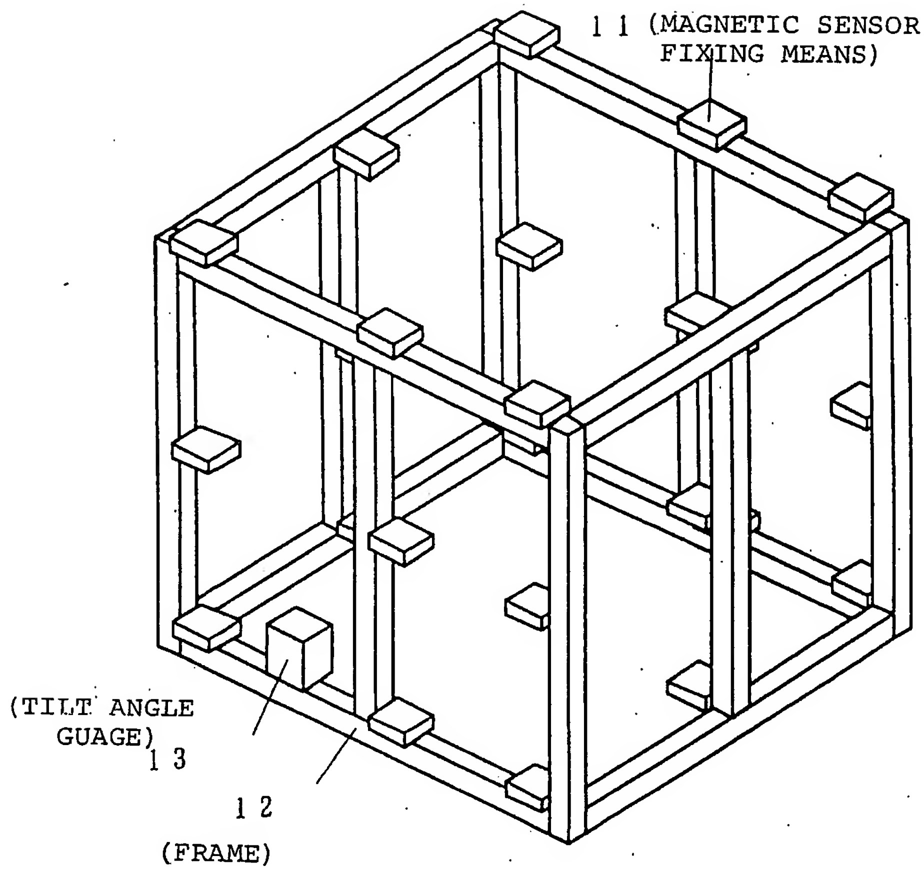
CORRESPONDING TO t_k IS SELECTED AS DIRECTION OF NOISE MAGNETIC FIELD

S146

TIME PERIOD WHERE SIGNAL MAGNETIC FIELD IS STOPPED IS OBTAINED AS DIRECTION OF NOISE MAGNETIC FIELD

END

FIG.32


1 1 (MAGNETIC SENSOR FIXING MEANS)
(TILT ANGLE GUAGE)
1 3
1 2
(FRAME)